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COST ANALYSIS

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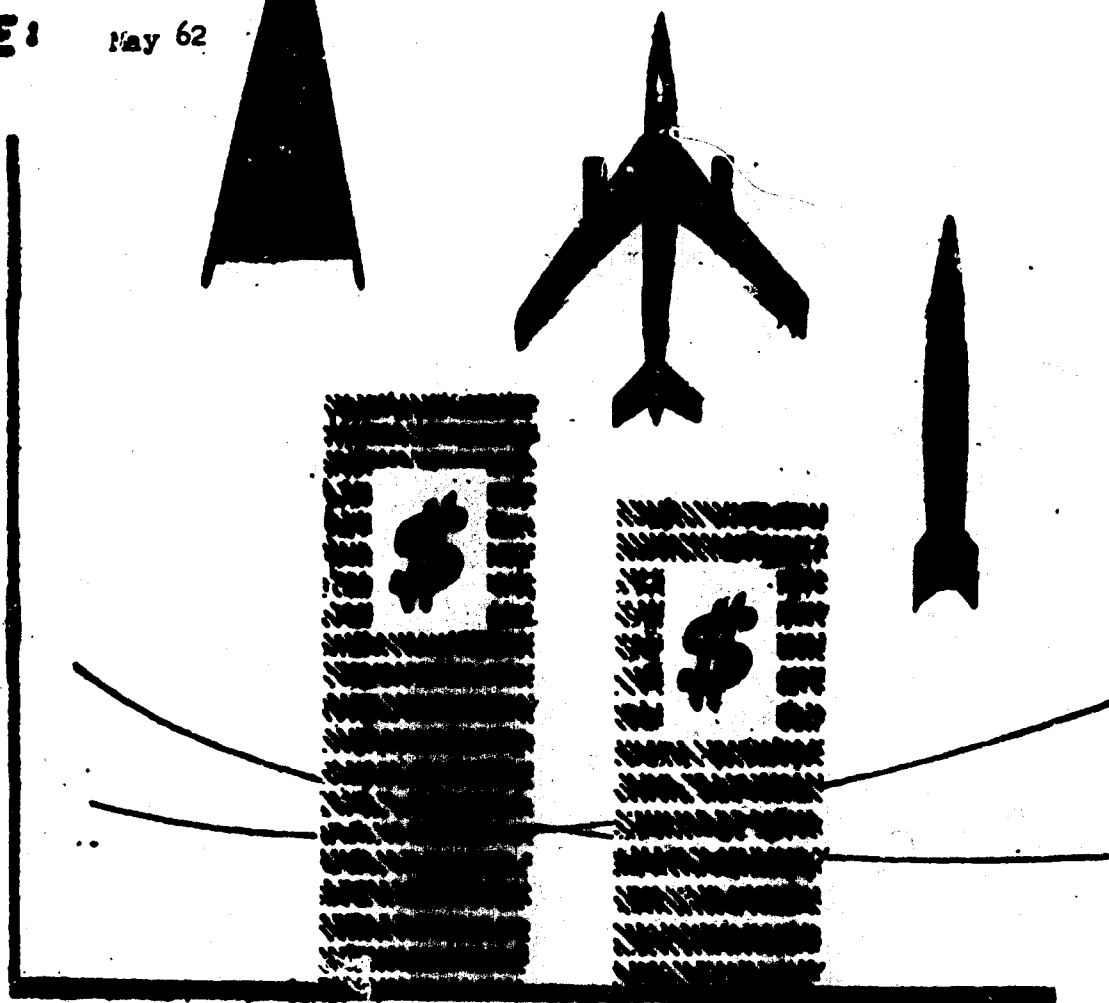


SUBJECT: COST PREDICTION BASED
ON GER UTILIZATION

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COST EFFECTIVENESS

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PREFACE

It has been generally recognized that a need exists for more precise and comprehensive methods of predicting weapon system total costs. This costing problem becomes greatly magnified in the case of postulated weapon systems which are radically different from any system on which actual cost data is available. Since historical costs provide the most reasonable basis for projecting future costs, it is desirable to develop historical data relationships. These relationships are generally referred to as Cost Factors or Cost Estimating Relationships (CER's).

The CER's are developed by gathering and processing historical data and applying various statistical techniques. This paper reviews the statistical techniques that are most appropriate for accomplishing this task and provides illustrations of the application of these techniques. Some of the pitfalls or difficulties in developing and utilizing CER's are also discussed.

This paper has been developed to assist the general AFSC effort to stimulate activity by the Divisions in developing CER's. It is also intended for discussion purposes by members of the "Statistical Techniques" Panel of the AFSC Cost Conference at Electronics Systems Division, L.G. Hanscom Field on 5-7 June 1962.

Cost Prediction Based on CR Utilization

Cost Estimating Problem

Similar problems are encountered by Air Force and Industry cost estimating personnel in the development of "accurate" cost estimates for advanced systems. All too frequently the cost analyst must prepare a program cost estimate for a newly conceived system based upon nebulous data - the configuration has not been identified, the statement of work is inadequate, and the time allotted for preparation and evaluation is unrealistic. However, these conditions can be expected to continue in advanced systems cost estimating, and the cost estimator must develop the ability to compensate for gaps in data by employing available statistical techniques and individual judgment.

Considerable contractor cost information is also available, both actual and planning type, which helps to expand the base for system cost predictions. This is an advantage that Air Force cost personnel have over their industry counterparts, in that the historical experience does not represent one source alone. The benefit of cost comparisons of the different contractors' estimates is therefore gained.

However, caution must be exercised in the use of any historical and current data. Changes in configuration, work statements, specifications, delivery schedules, or in other concurrent programs all produce significant effects upon cost. They must be recognized and identified before conclusions and recommendations are prepared based upon the available data.

System Cost Estimates

Total system costs result from the consolidation of the following three (3) programming categories:

- a. RDT&E (Research, Development, Test & Evaluation)
- b. Investment (Hardware production, initial training, supplies, etc.)
- c. Operations (Annual Operating Costs)

Each of the above programming categories must be further identified by Air Force fiscal year for the appropriate distribution of the total fund requirements in terms of New Obligation Authority required and/or anticipated expenditures.

In addition to presenting the System Cost Estimates as outlined above, USAF and DOD frequently demand extensive "back-up" and justification details to support the magnitude of the cost estimate. This has not been accomplished to the satisfaction of these staff agencies in the past. The specific cause of this dissatisfaction can be attributed to the conspicuous absence of the use of cost factors in the projection of the cost estimates. It is difficult to inspire confidence in an estimate when the cost estimator states that the cost estimate was developed from previous experience and judgment, and is unable to provide a progressive cost calculation in a logical step sequence commencing with selected basic data. However, this is very often the case.

Use of CER's in Cost Prediction

The problems outlined in the preceding paragraphs form the background for this discussion of cost prediction through utilization of cost factors or Cost Estimating Relationships (CER's). This technique or methodology is

essentially nothing more than a precise method of predicting costs of advanced systems based upon the development and utilization of CER's.

Development of CER's depends upon the availability of pertinent historical data. The necessary basic or historical data may cover a broad spectrum of information sources, both financial and non-financial. Data must be available, for example, which pertains to: Mission requirements, planned configuration, design and performance characteristics, AMPR weights, quantity and rate of production, logistics, and a multitude of other variables.

Obviously, discretion and judgment must be exercised in the application of CER's based on the cost estimator's knowledge of the specific cost problem and of the quality and validity of the basic data.

CER Derivation

First, what is a CER? It is a functional expression which states that the cost of an item may be predicted on the basis of one or more independent variables. This expression may be stated as: $C = f(X_1, X_2, \dots, X_n)$ where C equals cost and $X_1 \dots X_n$ may represent any number of cost predicting variables. The most common and widely used function is of the form $Y = bX$ where the total cost (Y) depends upon a variable X (where X may represent number of pounds, flying hours, etc.) multiplied by a constant (b) where b = cost per pound, cost per flying hour, etc.) This, of course, is an oversimplified case, but is illustrative of the potential utilization of CER's in the development and justification of cost estimates. The foregoing example is that of a linear function, or straight line relationship where the constant (CER) may represent "cost per person",

"Cost per flying hour", "cost per pound", etc. This function, in reality, is of the form $Y = a + bX$, where a , the fixed cost value, equals zero. This regression line, therefore, when plotted on graph paper will cross the Y axis at $Y = 0$. This indicates that there are no fixed costs included in this expression - only variable costs. Therefore, the total cost varies directly with the change in magnitude of the variable.

Usually, there are many situations in which total cost will include a constant fixed cost as well as an increment of variable cost depending on the value of the independent variable (the X value). In this case, if the trend follows a linear pattern, the function $Y = a + bX$ becomes an appropriate estimating equation for total cost.

The initial step, then in developing CER's is to evaluate and select the appropriate predicting variables. In order to do this, one must first know what types of costs are needed, and in what manner they should be structured. The formats in general usage today for consolidating total system costs are shown as Tables I, II, and III. In addition, other formats may be designed to fit the particular needs of a specific cost study.

Once the format has been established which outlines the types of costs needed, and the prescribed manner in which they must be grouped or segregated, a research program can be initiated with the objective of determining the significant variables which affect cost. As indicated previously, some of the commonly used variables for predicting costs are: weight, flying hours, speed, quantity, payload, etc.

It is not advisable to attempt to use every possible variable to predict a subsystem cost. Not certain all the variables may have an

insignificant effect on cost. In some cases, the effect on cost may be so negligible as not to warrant the effort to be expended. In order to reduce this task to manageable proportions, therefore, it is necessary to process the basic data that has been collected and then identify the most significant variables by means of a number of statistical techniques that are available.

TABLE I

Research and Development Costs

Design & Development

Preliminary Study and Design

Design Engineering

Hardware Fabrication

Tooling

Test & Evaluation

Vehicle Fabrication

Flight Test Operations

Test Equipment

Installations

Other Research & Development Costs

Depot Maintenance & Supply

Minor Modifications

Other

Total Research & Development Cost

TABLE II

Investment Costs

Installations

Equipment

 Primary Mission

 Specialized

 Other

Equipment Spares & Spare Parts

Initial Stock Levels

Initial Training

Initial Transportation

Initial Travel

Other

 Total Investment Cost

TABLE III

Annual Operating Costs

Equipment & Installations Replacement

Primary Mission Equipment

Specialized Equipment

Other Equipment

Installations

Maintenance

Primary Mission Equipment

Specialized Equipment

Installations

Pay & Allowances

Training

Fuels, Lubricants, and Propellants

Services and Miscellaneous

Total Annual Operating Cost

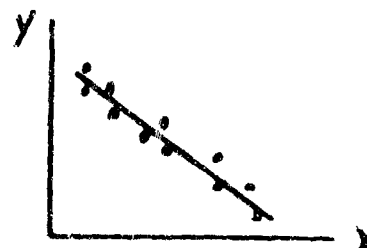
Selection of Significant Variables by Statistical Methods

After the basic data has been gathered, it must be statistically processed to enhance its validity for further research. Measures of central tendency (mean, median, and mode) should be applied to each series of data to determine the relative reliability of the data. These statistical measures highlight extreme or unusual values which should then be deleted from the series of data or adjusted on the basis of known causes for unusual deviations. For example, a given engine unit cost may be considerably higher in one year than in the preceding year although the quantity of engines is the same in both years. Normally, one would expect the unit cost in the second year to decrease if an equal quantity of engines is being procured. However, further study may reveal that the quantity of commercial engines on order in the second year was drastically reduced below the number on order in the previous year. This affected the unit cost of the engines being produced for the Air Force and caused the higher unit cost experienced. This unit cost should, therefore, be adjusted or deleted from the series of data.

Measures of dispersion (range, standard deviation, etc.) should also be applied to provide an estimate of the degree of variation of values in the series. The greater the amount of scatter which occurs about the average, the less predictable will be any projections of the data. For example, Case A below represents a much more predictable relationship than Case B:



Case A



Case B

Measurement of Relationship Between Two or More Series

Correlation and Regression Analysis

After each series of data (for every variable affecting weapon system costs) has been statistically processed, the relationship between any two or more variables may be measured mathematically. For example, assume that the cost of an engine is affected not only by the weight of the engine, but also by the thrust. If each of these parameters affected the cost equally and independently, it would be necessary to compute the relationship of the cost to both weight and thrust in order to derive the best estimating relationship. This is a much more involved computation than a comparison of cost to weight alone, or cost to thrust alone. It is, therefore, advisable to first determine the relationship of cost to each variable individually. If it is found that thrust bears only a slight degree of relationship to cost while weight is closely related to cost, it would only be necessary to compute this one relationship which is less rigorous than the comparison of three or more variables. This technique is generally referred to as Simple Correlation. It is known as Simple Linear Correlation if the change in one variable is at a constant ratio to the change in the other; if the change in one variable is at an increasing or decreasing ratio to the change in the other variable, the technique is called Simple Non Linear Correlation.

The general equation for computation of the simple coefficient of correlation is:

$$r = \frac{\frac{\sum(XY)}{N} - \left(\frac{\sum X}{N}\right)\left(\frac{\sum Y}{N}\right)}{\sigma_X \sigma_Y}$$

where X is the independent variable (in this case, weight of engine), Y is the dependent variable (unit cost of engine in this case)

$$\sigma_X = \sqrt{\frac{\sum(X^2)}{N} - \left(\frac{\sum X}{N}\right)^2}$$

$$\sigma_Y = \sqrt{\frac{\sum(Y^2)}{N} - \left(\frac{\sum Y}{N}\right)^2}$$

As an example of the application of the method to an Air Force cost problem assume the following hypothetical set of data for a group of engines which were developed through a typical growth progression:

Engine	Last Qty Procured	X Weight Per Eng (lbs)	Y Cost Per Engine
A	100	400	90,000
B	105	420	95,000
C	102	450	100,000
D	105	480	105,000
E	98	500	110,000

To keep this computation relatively simple and easy to understand, it will be assumed that since the quantities procured of each engine vary so slightly, the quantity variable need not be analyzed as a factor affecting the unit cost variations. Therefore, the computation of the relationship between X and Y using the formula for the coefficient of correlation (r) given in the previous paragraph results in $r = 0.9713$.

This indicates that the cost of any given engine of a weight within the ranges listed in the above table can be reasonably well predicted on the basis of its weight. The cost of an engine of a weight exceeding any of the weights listed, can also be estimated from this relationship, but with considerably less confidence. Whenever a variable is projected (extrapolated) beyond the range of existing historical data, a considerable amount of uncertainty is built into the result.

The computed relationship (r) can be used to develop a line of regression or estimating equation which will provide the basis for predicting, in this case, the unit cost of an engine of any given weight by substitution of the given weight in the equation.

The general equation for the linear line of regression where the coefficient of correlation has already been computed is:

$$y = r \frac{S_y}{S_x} x$$

where y is the deviation from its mean

and x is the deviation from its mean

$$y = 0.9713 \frac{(7071.0678)}{36.8781} x$$

$$= 180.8936 x$$

by substituting into the general equation the values previously computed.

but since $y = Y - \bar{Y}$ and $x = X - \bar{X}$

then $Y - \bar{Y} = 180.8936 (X - \bar{X})$

therefore $Y - 100,000 = 180.8936 (X - 450)$

$$\text{Ans: } Y = 18,597.8800 + 180.8936 X$$

This is the estimating equation for predicting an engine unit cost given any assumed weight. For example, what is the cost of a comparable engine weighing 600 pounds? Simply substitute the value of 600 pounds for X in the equation of the preceding paragraph as follows:

$$Y = 18,597.8800 + 180.8936 (600)$$

therefore: $Y = \$127,134$ (cost per engine)

However, suppose that engine thrust also has a significant, and independent effect upon unit cost. This implies that engine weight alone is not adequate as the sole predictor of the engine cost. The case now becomes one where two or more variables must be compared with cost, and requires the use of the technique known as Multiple Correlation. This technique involves a much more laborious computation than the simple correlation method which has been illustrated by a hypothetical application. A suitable example of the application of this method is, therefore, beyond the scope of this paper. Consequently, only the general equations are provided here for anyone interested in pursuing this form of analysis further:

Coefficient of Multiple Correlation

$$R_{123} = \sqrt{1 - \frac{[\sum(X_1^2) - b_{12.3} \sum(X_1 X_2) - b_{13.2} \sum(X_1 X_3)]}{N \sigma_1^2}}$$

Line of Regression or Estimating Equation (assuming a linear regression)

$$X_1 = a + b_{12.3} X_2 + b_{13.2} X_3$$

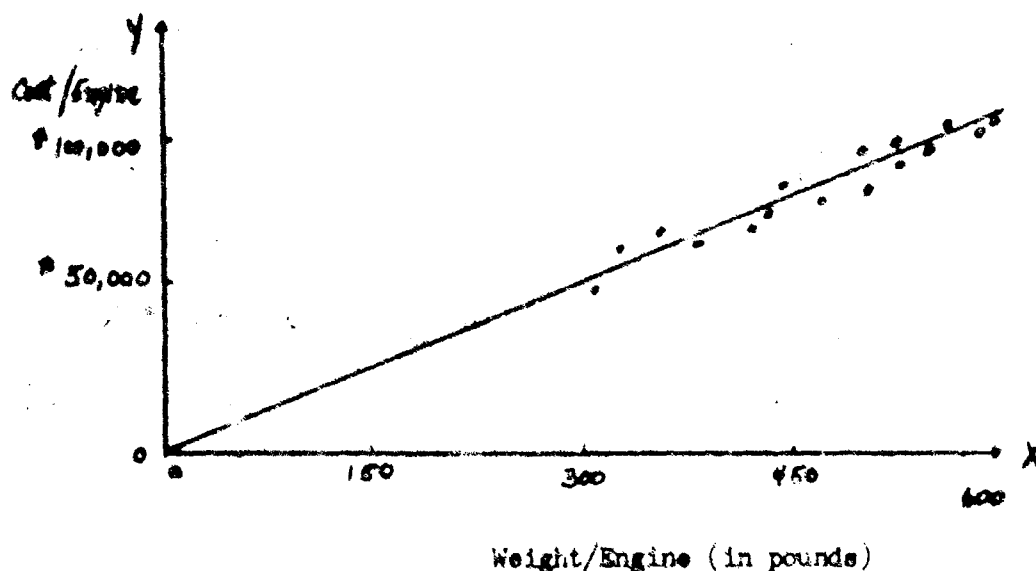
For a non-linear multiple correlation, the following general equation for the resulting non-linear regression line may be used:

$$X_1 = A + f(X_2) + f(X_3) + \dots$$

where $f(X_2, \text{etc})$ indicates any function² of X_2, etc . Such as a parabola, hyperbola or other type of curve.

Scatter Diagram

If it is desired to investigate the relationship between two variables without going through the involved mathematical procedure of computing coefficients of correlation, a device known as the Scatter Diagram may be used. The two series of values are plotted graphically on arithmetic graph paper with one variable (the independent variable) placed on the X axis and the other (the dependent variable-usually cost) on the Y axis. If there is a definite relationship resulting from plotting the associated variables on a chart, the points will follow a definite line of movement or "path" as follows:



If the relationship were perfect, each plot point would coincide with a computed line of best fit instead of being randomly scattered across the face of the scatter diagram.

In this example, the plotted points do not all fall on the straight line. Therefore, the relationship of the two variables obviously is not perfect. However, observation of the scatter and path of these points in relation to the line will indicate that in all probability a straight line will describe the data reasonably well. By initially using this method it can be determined whether a significant relationship exists between the variables before consuming an extensive amount of time performing the rigorous mathematical computations. This procedure may obviate the need for the mathematical computations if the result indicates a lack of significant correlation between the variables.

Ratios

Another well known, and widely used statistical technique is the ratio. A ratio expresses the relation of occurrence of a given kind of event to the occurrence of other events or of one kind of data to another. In formula form this measure is represented as:

$$\text{Ratio} = a/c$$

where: a = number of times the event occurs

c = number of times another event occurs

Ratios are particularly applicable in the development of cost estimating relationships. A simplified example is the method generally used in estimating manufacturing overhead costs. Overhead is almost always regarded as being a linear homogeneous function of direct labor cost.

This method of treatment obviously assumes that every item in the overhead category varies with direct labor cost. Although it is known that certain of these items do not (building depreciation, rent, etc.), the percentage-of-direct labor approach will probably continue to be used because of the ease of computation and justification.

A somewhat more involved application of ratios in developing CER's may again be illustrated by an example pertaining to estimating the cost of engines - one of the examples contained in a previous paragraph illustrated a method of computing a CER to estimate engine cost based on the parameter of engine weight. It was further indicated that engine thrust also appeared to have some influence upon engine cost. The method of multiple correlation, therefore, could be utilized to determine the total influence upon cost of both weight and thrust. However, if engine costs are examined as a function of the dry weight of the engine divided by thrust (the so-called specific weight) the same amount of cost variation can be explained by utilizing the less complicated simple correlation technique. Here the ratio technique has been used to reduce the number of independent variables from two sets (weight and thrust) to one (specific weight), thus reducing the amount of work required to derive a cost estimating relationship.

Example:	Engine	Weight (pounds)	Thrust (SHP)	Weight/Thrust X	Cost/Engine Y
	T 56	2930	3700	0.79	\$120,000
	T 58	300	1250	0.24	60,000
	J 85	1400	4000	0.35	90,000

Index Numbers

Still another commonly used statistical technique and vital tool of the cost estimator is the index number. An index number is a statistical device for measuring changes in groups of data. It is of particular value when applied to the yearly changes in the price level. This measurement is known as a price index. It provides the basis for adjusting any prior year series of cost data to current dollars or to any other desired basis. This is obviously an important tool for use in cost comparisons, such as the total costs of two competing systems, etc. (See Table IV)

CER Development by Component Level or Cost Element

CER's may be developed either at the total subsystem level (e.g., airframe, propulsion, electronics) or at the major cost element level (e.g., labor, materials, overhead.) However, regardless of the level of detail desired, an initial separation must be made between those costs that are recurring and those that are one-time costs or non-recurring. Examples -- non-recurring costs are initial engineering and tooling, engineering tests, and test vehicles. Recurring costs are those costs which continue over the life of a production run and are allocable on a per unit basis. The major portion of the DT&E costs of an estimate are non-recurring costs. The investment cost portion of an estimate includes a much smaller percentage of non-recurring costs--production tooling is generally the major expenditure in this category. Although it is more difficult to develop cost estimating relationships for non-recurring costs, estimating methods applicable to these types of costs will be discussed.

TABLE IV

AIRCRAFT MATERIAL PRICE INDEX

Year	Index (1954 = 100)	Factor to Raise to 1961
1945	51.6	243.0
1946	57.9	217.5
1947	71.6	175.9
1948	79.5	158.5
1949	81.5	154.8
1950	84.5	149.7
1951	93.7	134.9
1952	94.7	133.7
1953	98.8	128.1
1954	100.0	126.8
1955	103.8	122.0
1956	109.2	116.1
1957	119.1	106.8
1958	120.4	105.5
1959	123.4	103.1
1960	125.2	101.6
1961	126.5	100.0

Cost estimating relationships in use today generally relate cost to quantity and component weight. The effect of quantity and weight is considered in the cost estimating of all aircraft components. However, very little effort seems to have been devoted to studying the effect on cost of the many technical and performance characteristics of weapon systems. This is probably due at least partially to the difficulties encountered when the relationships involving more than two variables are measured. The effects of interactions between independent variables must be determined in order to obtain a valid estimate of total explained cost variation. However, this is a complicated and time consuming effort and requires an extensive amount of data which usually is not available.

The relationship between the cost of producing a component and the number of components produced is usually referred to as a "progress curve" or "learning curve" as defined earlier in this paper. In general, the learning curve effect is a decrease in recurring production costs as the number of units produced increases.

Next to quantity, weight appears to explain more variations in component cost than any other physical characteristic. There have been many regression studies relating weight to cost which, at a given quantity, have indicated the validity of this relationship. However, in the case of electronic equipment, this relationship does not hold true. The cost of electronic equipment is still continuing to rise and miniaturization has caused cost per pound to go up. This in itself indicates that cost per pound is a poor relationship for estimating the cost of electronic equipment at this time. In general, the estimator must use the cost of

similar types of electronic devices as a base for estimating the cost of new equipment. This is known as "pricing by analogy".

Although it is generally preferable to estimate costs on the basis of the major component elements (labor, materials, and overhead), the airframe portion is usually the only component estimated on this basis. This is due to the fact that seldom is adequate data available to estimate engine and electronics costs at this level of detail.

Airframe Cost Estimating Relationship

Non-Recurring Costs

Estimating the cost of an airframe requires a breakdown into two parts. One part includes all non-recurring costs; the other, all recurring costs. Most of the recurring costs are accounted for by manufacturing and most of the non-recurring costs by initial tooling and engineering, and flight test. Airframe weight is the parameter in general usage today for estimating both recurring and non-recurring airframe costs.

Studies of non-recurring airframe costs are being conducted in order to attempt to develop a more valid predictor of this category of costs. However, for the present, a reasonable method for estimating total non-recurring cost is by developing non-recurring cost versus airframe weight curves. This total cost can then be subdivided into initial tooling and engineering, and flight test costs on the basis of past cost distribution experience.

Recurring Costs

Manufacturing costs, as stated previously, account for the major portion of recurring costs. The principal cost elements of manufacturing are materials, direct labor, and overhead.

Cost-weight curves or regression estimating equations may be developed to estimate the airframe materials cost based on any given airframe weight. This relationship would be subject to certain adjustments in the event a more exotic material is substituted for the type of material upon which the CER was based. Figure 1 presents a typical cost-weight curve for airframe material.

The direct labor involved in manufacturing an airframe is defined to include all hours expended on fabrication, sub-assembly, final assembly, and testing. These direct manhour expenditures are kept up to date and reported quarterly in an AFSC document entitled "AMPR/MMFR, Quarterly Tabulation - Basic Productivity and Utilization Data from Producers of Aircraft, Missiles, and Major Supporting Sub-Systems". The manhours are reported as "on and off-site direct man-hours" in order to give consideration to the off-site manhours which reflect the amount of airframe sub-contracted. It is generally felt that this data provides a sound basis for estimating airframe direct labor cost. The most useful cost estimating relationship for this cost element has been the cost-weight curve. An example of this type of curve is given in Figure 2.

Manufacturing overhead is generally regarded as being a linear function of direct labor cost. Although certain items in the overhead category do not vary with direct labor cost, this percentage-of-direct labor method

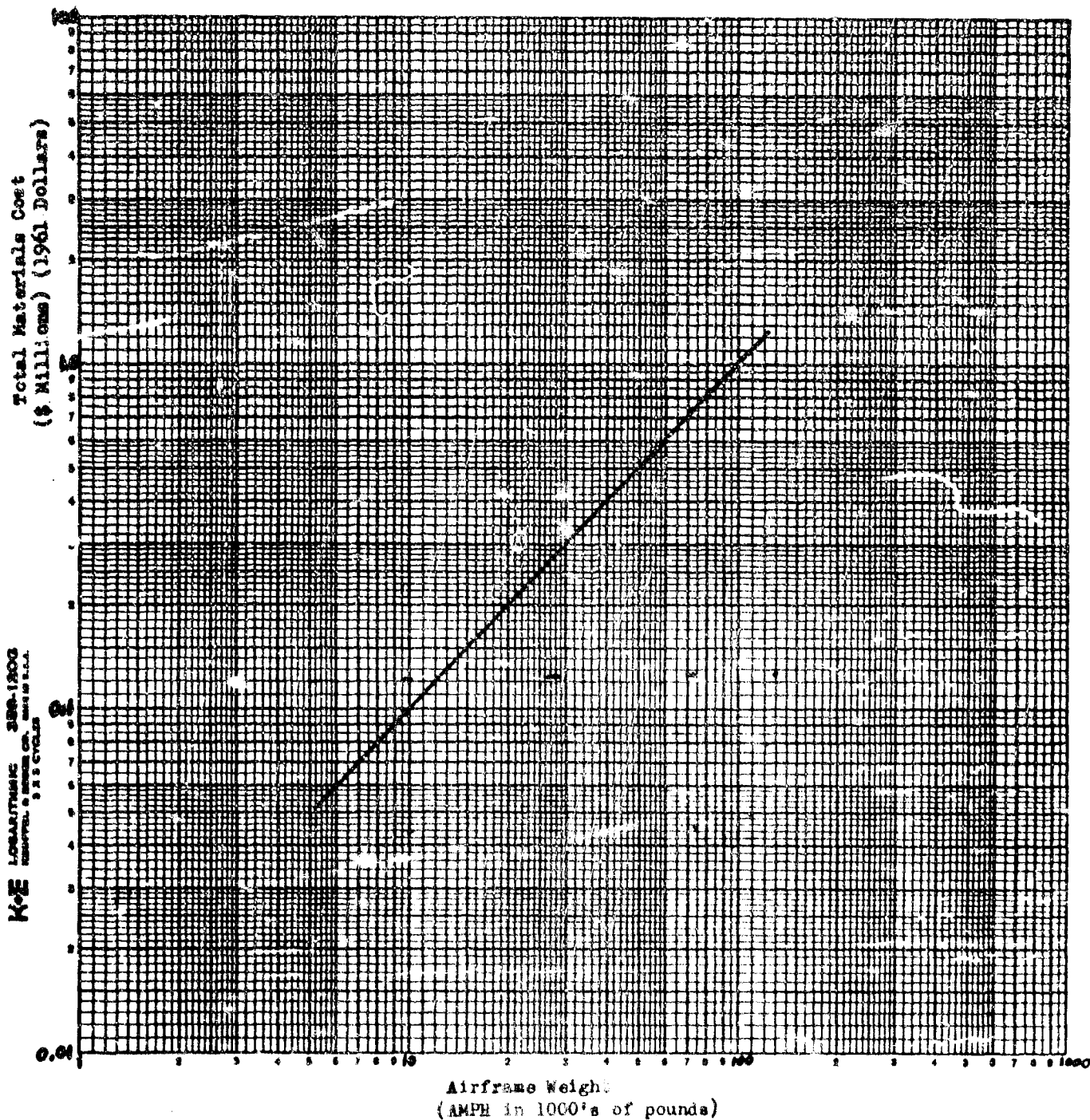


Figure 1: Total Recurring Materials Cost As A Function of Airframe Weight
(Standard Aluminum Construction)

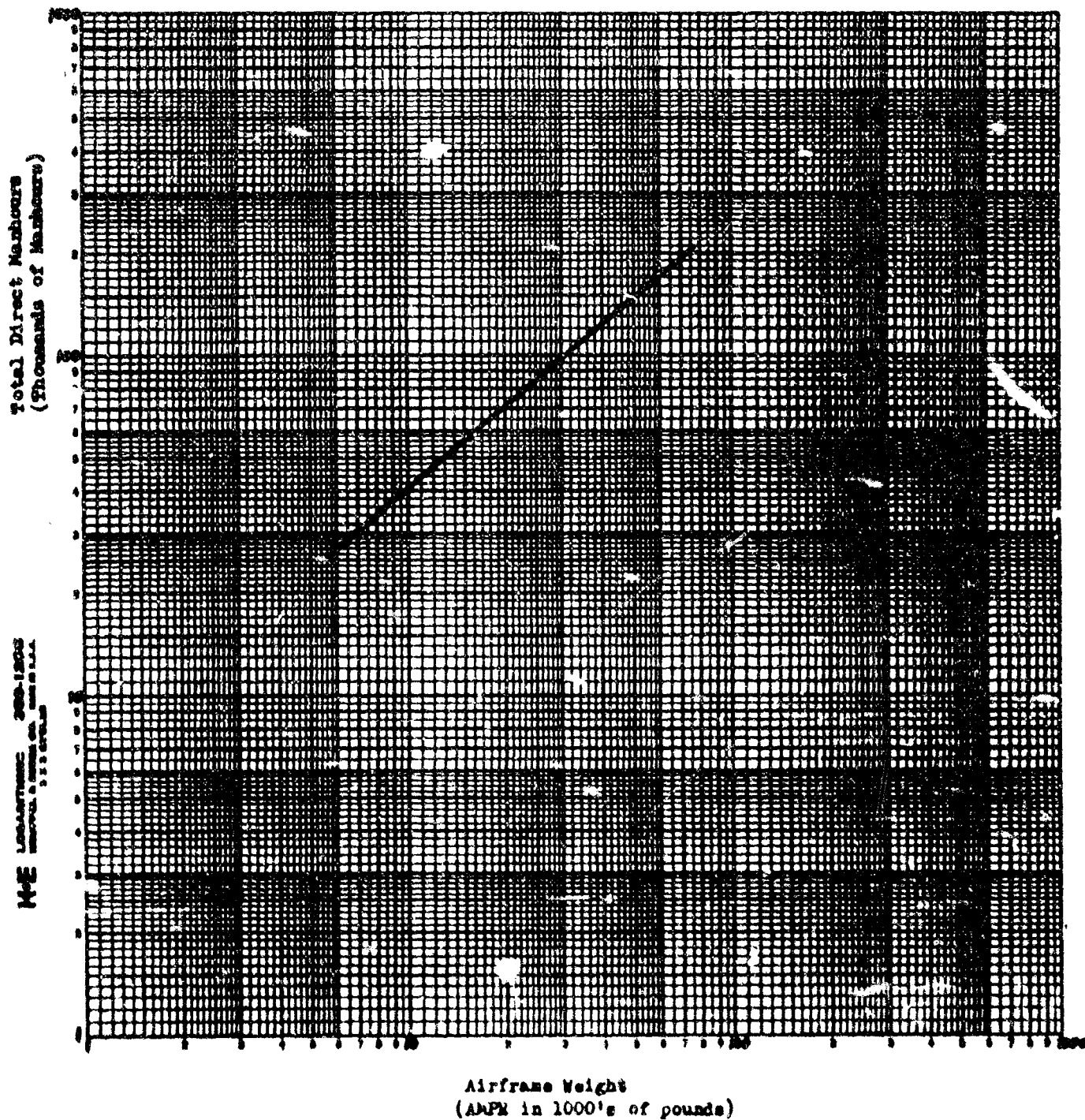


Figure 2: Total Recurring On/Off Site Direct Manhours As a Function of Airframe Weight (Standard Aluminum Construction - Subsonic)

appears to be the most satisfactory cost estimating relationship currently available. Review of available data contained in Air Force contracts indicates that within the airframe industry the overhead rates in general use appear to be within the range of 150-200% of direct labor cost.

In addition to manufacturing cost, another fairly significant recurring cost item is "Sustaining Tooling and Engineering". As a result of considerable statistical analysis, it appears that the most appropriate measure of this cost element is its relationship (in terms of percentage) to manufacturing cost. A range of 20 to 30% of manufacturing cost is considered to be a reasonable approximation.

Engine and Other Subsystem Cost Estimating Relationships

Airframe costing techniques are not applicable to costing of engine and other subsystems. The distribution of labor hours is usually quite different. Also the amount of cost detail available for airframes is seldom available to the same extent for the other subsystems. The method generally used for predicting engine costs, therefore, is to develop a cost estimating relationship of engine cost to the ratio of engine dry weight divided by engine thrust, or the engine specific weight. This may be accomplished by the Correlation and Regression Analysis technique which was described previously in this paper, or by use of the Scatter Diagram. Figure 3 presents an example of turbojet engine costs plotted as a function of specific weight.

Subsystems (exclusive of engines) do not appear to follow any cost-weight or any other statistical relationship by which costs could be predicted from any given parameter. The most common method for predicting these subsystem costs has been "costing by analogy"; that is, projection from these costs of comparable existing subsystems by the application of complexity factors to account for increased sophistication in the system above the basic system.

Examples of CFR's for predicting DT&E and investment costs.

1. Airframe design engineering cost as a function of airframe weight.
2. Airframe hardware fabrication as a function of airframe weight.
3. Airframe manufacturing facilities cost as a function of airframe diameter.
4. Engine design engineering cost as a function of specific weight.
5. Airframe direct labor cost per pound of airframe weight as a function of cumulative output and/or rate of output.
6. Manufacturing overhead cost as a percentage of direct labor cost
7. Material cost per pound as a function of cumulative output.
8. Subsystem spares cost as a percentage of initial investment cost.

Annual Operating Costs

Annual operating costs are recurring costs which continue over the life of a system. The major cost elements as illustrated in Table III are:

1. Equipment and facilities replacement
2. Equipment and facilities maintenance
3. Pay and allowances
4. Training
5. Fuels, lubricants, and propellants
6. Transportation
7. Travel
8. Other services

A number of cost estimating relationships have already been developed and are available in the USAF Planning Factors Manual AFM 172-3. These relationships are constantly being revised or replaced as more operating command experience becomes available. The CER's are generally of the form: cost per person, cost per flying hour, or cost per squadron.

Pay and allowances costs are usually computed on the basis of an average annual cost factor per man, for example, \$6000 per man. The total annual cost may then be increased by an arbitrary percentage based on the assumed turnover rate.

Equipment and facilities replacement and maintenance are usually predicted on the basis of the expected annual flying hours per aircraft.

Training costs are based on Air Training Command experience factors of training cost per man.

POL costs are also determined from the annual flying hours and specific fuel consumption per engine.

The other items are generally based on a factor of cost per man.

Summary

The CER's that have been developed to date are largely directed toward predicting recurring costs. This, therefore, provides fairly adequate coverage of the Investment and Annual Operating cost categories. However, the DT&E area, which consists primarily of non-recurring cost items, does not have currently available CER's to provide the same cost prediction capability. This has been, and will continue to be, a difficult area for developing cost estimating relationships because regression techniques and other statistical methods do not logically apply to these types of costs. Studies are continuing, however, which hopefully will result in the development of at least some CER's needed to inject a measure of validity into DT&E cost estimates.